10. ECONOMIC IMPLICATIONS OF RETROFITTING 707-320B AIRPLANES WITH ACOUSTICALLY TREATED NACELLES

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SUMMARY

This paper presents the results of a theoretical economic study that compares two fleets of Boeing 707-320B airplanes, one with and one without acoustically treated nacelles described in earlier papers. The treated nacelle includes a two-ring treated inlet and a full-length treated fan duct. The study included evaluation of a hypothetical airline 707-320B route network operating with a representative passenger fare yield structure. The results of this study are applicable only to the route structure assumed. Any specific airline having a significantly larger proportion of long-range routes, higher passenger load factors, or inclusion of cargo would be more severely affected by the treated nacelle. The results of this study show that the 1972 direct operating costs (DOC) will increase by about 9.2 percent and that this increase is almost entirely due to the depreciation cost of the retrofit itself.

It was found that when operating both airplane fleets at the current maximum gross take-off weight of 327 000 lb, the airplane with the treated nacelle presented some operational restrictions that produced a small reduction of revenue earning capacity. The major factor in economic return was the increase in DOC. This resulted in a reduction in return on revenue of 4.4 percent. This 4.4 percent reduction for the hypothetical carrier assumed may appear small. However, in a narrow-margin industry, a nominal cost increase can produce a drastic impact on return on investment. In the final analysis, a detailed assessment of the economic effect of a treated nacelle retrofit must be made by each of the affected airlines.

INTRODUCTION

The development and performance of a nacelle with a two-ring treated inlet and a full-length treated fan duct have been described. (See figs. 1 and 2.) The program demonstrated noise level reductions of 15.5 EPNdB at the landing-approach power condition, 3 EPNdB at take-off power, and 5.5 EPNdB at cutback power. Although these results are based on tests made on an airplane powered with Pratt & Whitney JT3D-7 engines, the results are directly applicable to the 707-320B powered with Pratt & Whitney JT3D-3B engines, when proper account is made for the performance differences between the two engines.

The economic impact of the nacelle modifications on all the airline operations has been studied in two separate stages. First, the increased DOC for the 707-320B powered with P&W JT3D-3B engines has been assessed. Second, the economic effect on a hypothetical airline operation has been studied. The study is theoretical and necessarily limited in its scope. It does not attempt to answer important questions such as whether the airlines can absorb the cost of such a program without attendant increases in income. McCormick (paper no. 8) has shown that the major performance effect due to the nacelle treatment was a loss of capacity payload range of approximately 200 nautical miles. This loss in range was due mainly to the fuel displaced by the increased operating empty weight of 3140 lb.

DIRECT OPERATING COST

The DOC was estimated according to the 1967 Air Transport Association (ATA) cost formula with specific modifications to cover the special case of a treated nacelle retrofit. The changes concern costs due to maintenance, depreciation, and airplane utilization. The costs used in this study are intended to be representative of the year 1972. For this reason, maintenance labor rate was assumed to be $5 per hour (a 25 percent increase over the ATA formula), and material costs were assumed to be increased by 20 percent over the ATA formula. A theoretical analysis has been made of the maintenance costs for a production version of the nacelle including a thrust reverser installation. When the additional costs due to inspecting, cleaning, repairing the treated areas, and the increased handling problem (extra weight) were taken into account, the estimates showed that the nacelle maintenance cost would be increased from $2.70 per nacelle per flight hour for the existing nacelle to $3.02 for the treated nacelle (1972 prices).

While the assumed airplane depreciation conformed with the ATA method, the modified nacelles were depreciated over a 5-year period. This period was chosen to reflect the fact that by 1972 the airplanes will be partially depreciated. No residual value was assumed for the existing nacelles. Spares provisioning for the treated nacelles was taken to be 20 percent to reflect the current lack of operational experience with treated nacelles. The ATA formulas state a 10 percent provision for the airframe including the nacelles and 40 percent for the engines. An airplane utilization of 3800 hours per year was considered to be a representative figure for the route systems commonly flown by the 707-320B/C type airplanes.

There are uncertainties in estimating retrofit cost, mainly with respect to production techniques for the polyimide fiberglass acoustic material, date of go-ahead, number of kits produced, the production rate, and method of performing the installation. However, on the basis of an assumed total of 400 airplane sets manufactured to the production

schedule given in figure 3, the current estimate for a 1972 price is $1 000 000 per airplane including installation (fig. 4). Retrofit installation is assumed to be concurrent with normal major overhaul periods. If this assumption is proved to be incorrect, additional costs for airplanes out of service will have to be included. Table 1 lists some of the important assumptions. All others not listed were as prescribed by the 1967 ATA formulas.

Figure 5 shows DOC for international operations, both for the current production airplane and the treated-nacelle airplane. These data are based on a Mach number of 0.83, which is the Mach number currently used for minimum-cost cruise, except at the long-range extreme, where a cruise Mach number of 0.80 is used. Figure 6 shows the percent increase of DOC for both international and domestic operations due to the incorporation of the nacelle modifications. The increases are about 9.2 and 9.6 percent for the international and domestic rules, respectively.

Figure 7 shows how the various elements of cost contribute to the total cost at CAB distances of 2500 nautical miles. Although insurance, maintenance, and fuel contribute increases, 84.5 percent of the total increase stems from the depreciation cost of the treated nacelle. The following table gives the elements of DOC increase for a CAB distance of 2500 nautical miles:

	Percent of total increase
Crew pay	0
Fuel	8.9
Insurance	4.8
Maintenance	1.8
Depreciation	84.5
	100.0

Thus, the retrofit price and period of depreciation for the nacelle are of primary concern.

AIRLINE ECONOMIC STUDY

Basic Methodology and Assumptions

The operation of a fleet of Boeing 707-320B airplanes was simulated over the hypothetical route network shown in figure 8. This network includes U.S. to Hawaii, Transatlantic and beyond to the Far East, and domestic through routings from both. Passenger demand, trip frequencies, and load factors for each segment of the route system are representative of the period 1967-1968. The load factors are as follows:

Route sector	Load factor, percent	
	Summer	Winter
U.S. to Hawaii	61.0	50.2
U.S. through flights from Hawaii	61.0	50.2
U.S. through flights from Transatlantic	55.1	41.0
Transatlantic and beyond	64.6	64.9
Fifth freedom	43.0	31.0

The assumption of a fleet of 115 airplanes resulted in an average annual utilization for the existing airplane of 3785 hours. Note that the utilization is approximately the same as that used in the DOC study. The slight difference is due to the requirement to have a whole number of airplanes in the fleet study. As in the DOC study, minimum-cost techniques were assumed throughout, that is, a cruise Mach number of 0.83, except where range considerations were found to be critical. In this event, a long-range cruise Mach number of 0.80 was assumed.

Indirect operating costs (IOC) were calculated for the existing airplane by a method devised by Boeing and Lockheed and updated by Boeing in 1967. The individual items considered by the method are as follows:

1. Passenger service
2. Passenger and baggage handling
3. Aircraft servicing
4. Aircraft control
5. Servicing administration
6. Reservations and sales
7. Advertising and publicity
8. Maintenance burden – ground equipment
9. Depreciation – ground equipment
10. General and administrative

Each item was studied individually to estimate the increase, if any, due to the retrofit of the treated nacelle. Emphasis was placed on the maintenance and aircraft servicing and the depreciation of additional ground equipment. However, the total increase of indirect operating cost, when apportioned over an assumed 5-year period for the entire fleet, was found to be a small percentage of the total IOC.

With the use of a special computer program designed to model an operation, passenger demand and airfield temperature were described in statistical terms. Occasionally peak demands would occur simultaneously with high airfield temperatures; consequently,

passenger denials for certain long range flights were necessary. The unrestricted maximum gross take-off weight used was 327 000 lb for both airplane fleets. The maximum landing weight was 207 000 lb.

Pertinent CAB passenger-yield data were analyzed to derive the curves shown in figure 9. These were used together with the operating costs estimated for 1972 to determine the change in profit margin for the airplanes with the treated nacelles.

Results

Figure 10 shows the CAB distance percentage distribution resulting from the route-system and passenger-demand assumptions made in the study. Other operational quantities resulting from the simulated fleet operation are summarized in table 2. In particular, it will be noted that for a given number of trips, the airplane maintains substantially the same service level for the route system under study. In fact, the reduction of passengers carried is 0.05 percent. The increase of passenger denials occurs on three of the long-range westbound flights. A comparison of the related economic quantities for the two fleets is presented in table 3. The revenue earned is reduced by 0.10 percent. Direct operating costs increase by 9.6 percent and total operating costs by 4.4 percent. Essentially the whole of the operating cost increase is attributable to the increase of DOC. The net result of these revenue and operating-cost changes is to reduce the return on revenue, based on passenger yield only, by 4.4 percent.

In interpreting these results, two points need to be emphasized. First, the maximum stage length for the route system studied falls in the range from 4500 to 4750 nautical miles. The fleet operation of this hypothetical study was not greatly affected by the reduction of capacity payload range due to the treated nacelles. A system with a higher content of long-range routes would demonstrate a greater sensitivity to the nacelle modifications and would undoubtedly show a greater economic penalty. Second, for the purpose of estimating operating costs for the year 1972, the assumption has been made that the complete fleet of 115 airplanes will be retrofitted. The price estimate for retrofit has assumed that the retrofit will occur concurrently with normal overhaul periods in order to minimize airplane out-of-service times. Consequently, retrofit operations will be spread over a period of time greater than 1 year. The production schedule of figure 3 also indicated that it will not be possible to retrofit all Boeing 707-320B/C models by the end of 1972. The cost implications of a slide in retrofit scheduled beyond 1972 must be evaluated by each airline.

Noise Level Distribution

For the fleet operation studied, frequency distribution of noise levels experienced during take-off and landing approach can be estimated. This is shown in figure 11 for the landing approach and figure 12 for take-off climbout. It can be seen that the treated nacelle shifts the landing noise from the 118-121 EPNdB band to the 103-106 EPNdB band at a point 1 nautical mile from the landing threshold.

Because of the wide spread of take-off weights, the take-off noise levels are distributed over a range of EPNL. No estimates are shown below 85 dB because of the lack of test data at the low EPNdB levels. These data, as measured on P&W JT3D-7 engines, have been assumed to be applicable to the P&W JT3D-3B engine of this study. This has been confirmed by other Boeing flight-test measurements. Figure 12 shows that the frequency of noise level experienced at the 3.5 nautical mile point above 100 EPNdB, for instance, is reduced from 31 percent of the total number of flights to 14 percent.

CONCLUDING REMARKS

The economic impact of nacelle modifications to reduce airplane noise have been studied for the Boeing 707-320B powered with Pratt & Whitney JT3D-3B engines. The modifications comprise a two-ring treated inlet and a full-length treated fan duct. The increase of airplane operating empty weight would be 3140 lb and this leads to the major effect on performance, that is, a capacity payload range loss of approximately 200 nautical miles due to the available fuel displaced. The major economic effects of the above changes are as follows:

(1) A total installed retrofit cost of $1 000 000 based on a production run of 400 airplane sets.

(2) An increase of international direct operating cost of 9.2 percent, due mainly to the treated-nacelle depreciation costs. In this study, the depreciation period of the treated nacelle has been assumed to be 5 years.

(3) Small reduction of revenue earning capacity for the airline route structure and stage-length distribution assumed in this study. The revenue loss would increase for a route structure with a higher content of long-range stages.

(4) A reduction in return on revenue of 4.4 percent for the case considered.

Further work is necessary in the following areas:

(1) Validation of retrofit price estimates, particularly as affected by design and production techniques for polyimide fiberglass acoustic panels.

(2) Validation of in-service performance of the acoustic panels and the associated maintenance cost.

(3) Consideration of the cost effects of a retrofit schedule extending beyond 1972.

(4) Consideration of the case of an airline route system with a higher content of very long-range stages.

TABLE 1.- ASSUMPTIONS FOR DOC STUDY

Airplane:	
Airframe	Boeing 320B
Engines	P&W JT3D-3B
Seats	149
Maximum gross take-off weight, lb	327 000
Flight operations:	
Cruise altitude, ft	31 000, 35 000, and 39 000
Cruise technique	Step climb where applicable
Cruise Mach number:	
Minimum cost	0.83
Long-range extreme	0.80
Utilization, hours/year	3800
Maintenance:	
Labor rate, dollars/hour	5
Operating empty weight, lb, for -	
Existing airplane	145 100
Airplane with treated nacelles	148 240
Material costs	ATA plus 20%
Nacelle maintenance cost, dollars per flight hour per nacelle, for -	
Existing airplane	2.70
Airplane with treated nacelles	3.02
Downtime penalty for retrofit	0 (accomplished during base maintenance)
Depreciation:	
Period for airframe, years	12
Period for treated nacelle, years	5
Spares provisioning for treated nacelles	20%
Retrofit price, dollars	1 000 000

TABLE 2.- OPERATIONAL COMPARISONS

Operational quantity	Airplanes with –	
	Existing nacelles	Treated nacelles
Average trips per week	1753	1753
Utilization hours per year	3785	3786
Average number of passengers per week . . .	127 963	127 895
Average load factor, percent	48.99	48.97

TABLE 3.- ECONOMIC COMPARISONS

[Based on annual total figures]

Economic quantity	Percent change after retrofit
Passenger revenue	-0.10
Direct operating costs	+9.6
Indirect operating costs	Negligible
Total operating costs	+4.4
Reduction in return on passenger revenue	-4.4

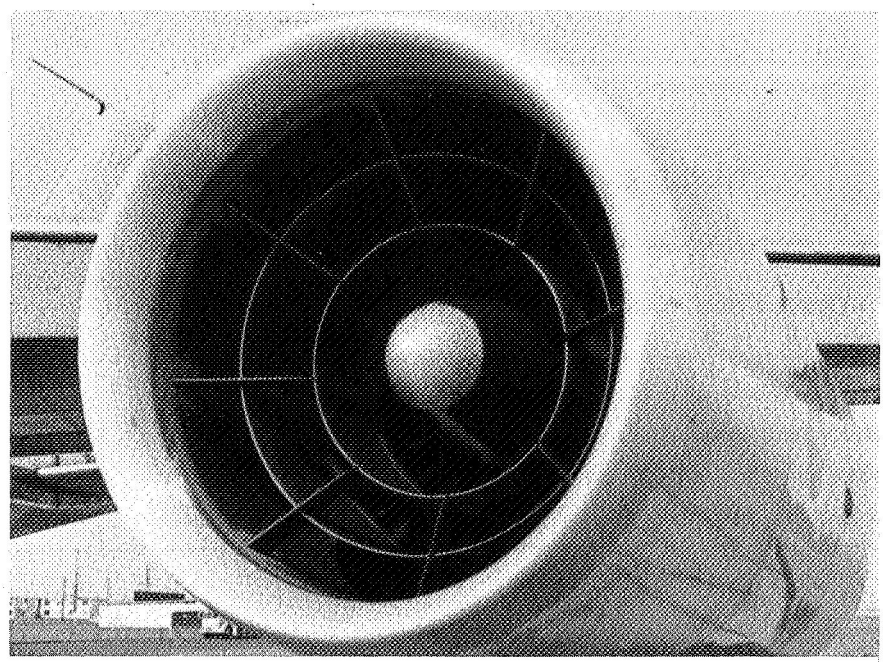

Figure 1.- Treated nacelle installed on 707-320B airplane, front view.

Figure 2.- Treated nacelle installed on 707-320B airplane, side view.

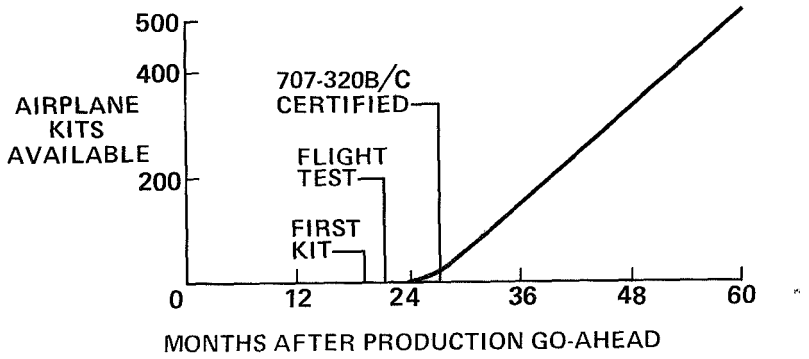

Figure 3.- Retrofit kit production schedule.

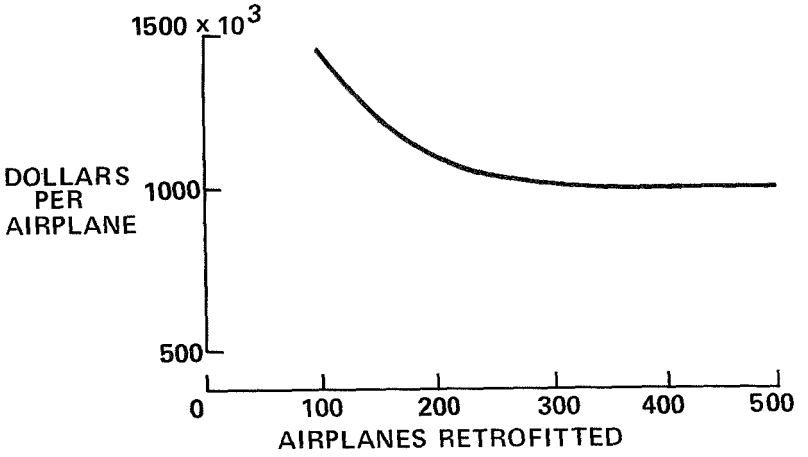

Figure 4.- Retrofit price.

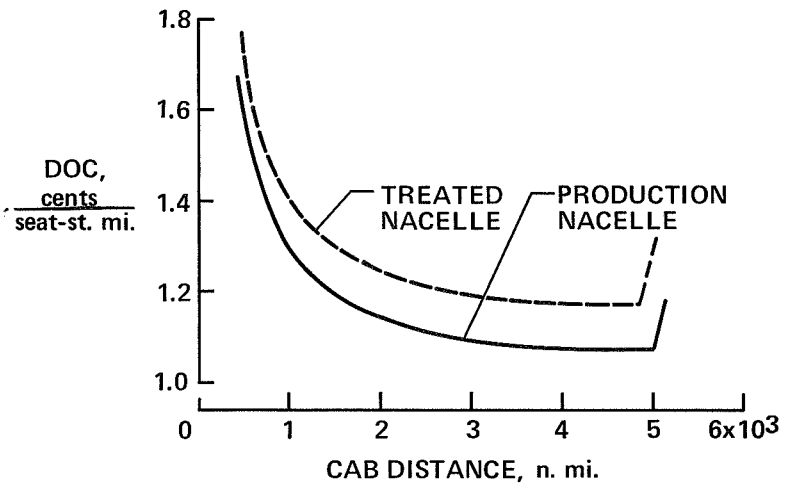

Figure 5.- Direct operating costs for 707-320B with P&W JT3D-3B engines. ATA international operations.

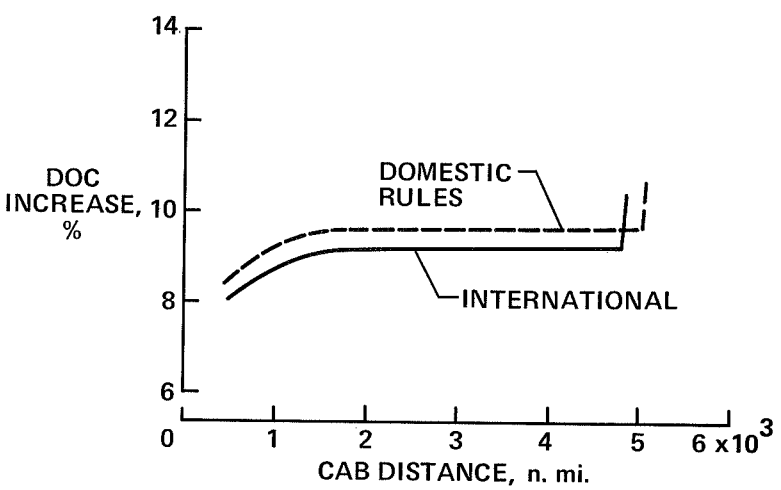

Figure 6.- Increase of direct operating cost due to nacelle treatment.

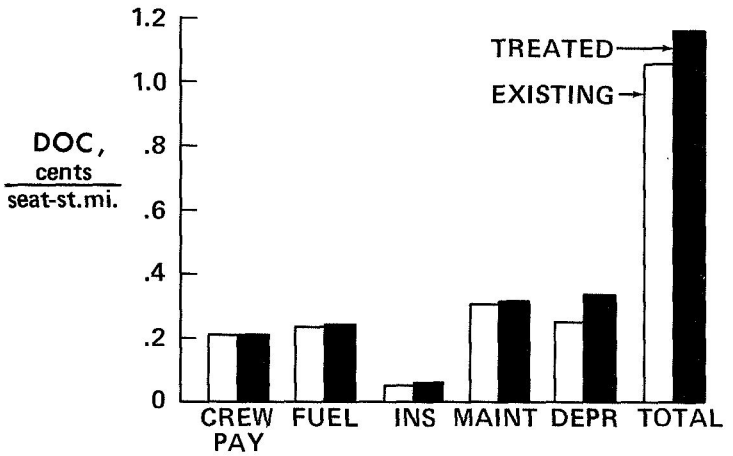

Figure 7.- DOC elements. CAB distance, 2500 nautical miles.

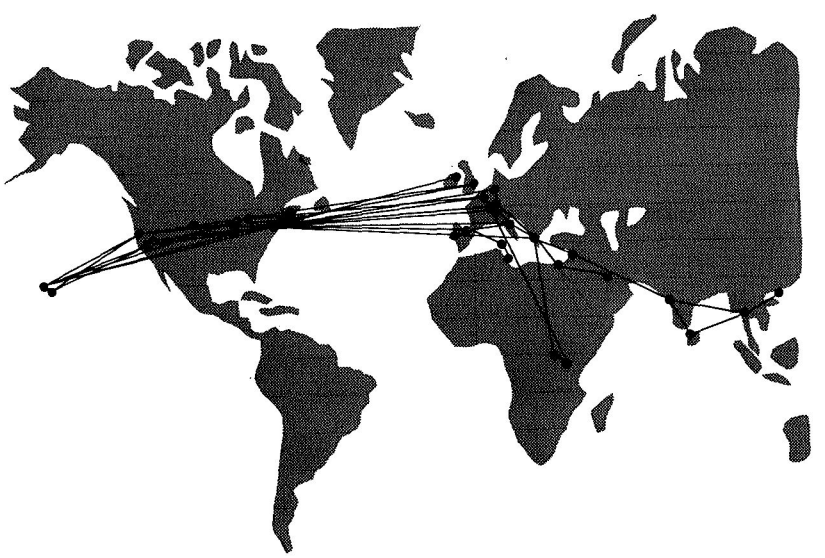

Figure 8.- Airline route system.

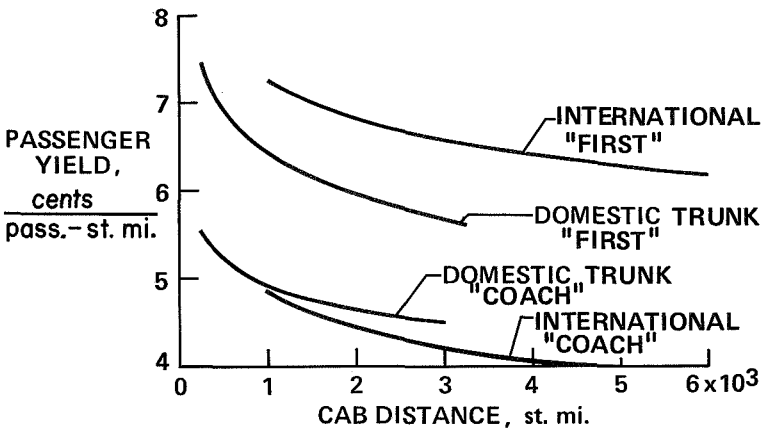

Figure 9.- Passenger fare yield.

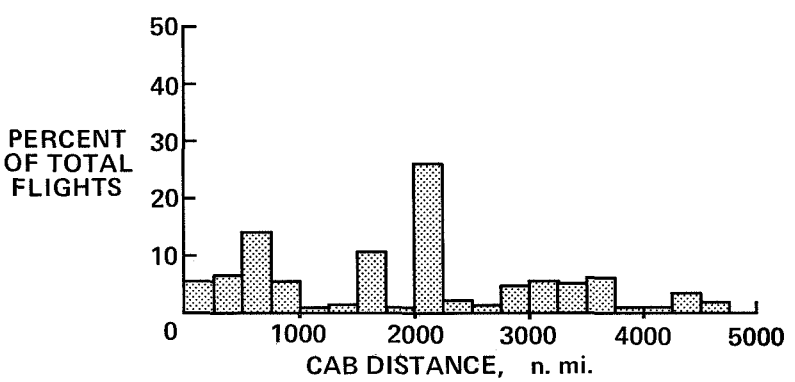

Figure 10.- Distribution of CAB distance.

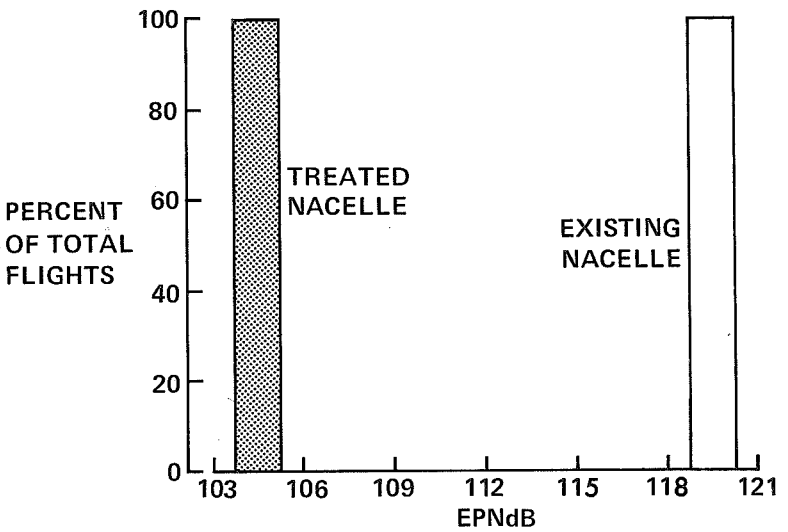

Figure 11.- Approach noise level distribution at 1 nautical mile from landing threshold. 707-320B; P&W JT3D-3B engines.

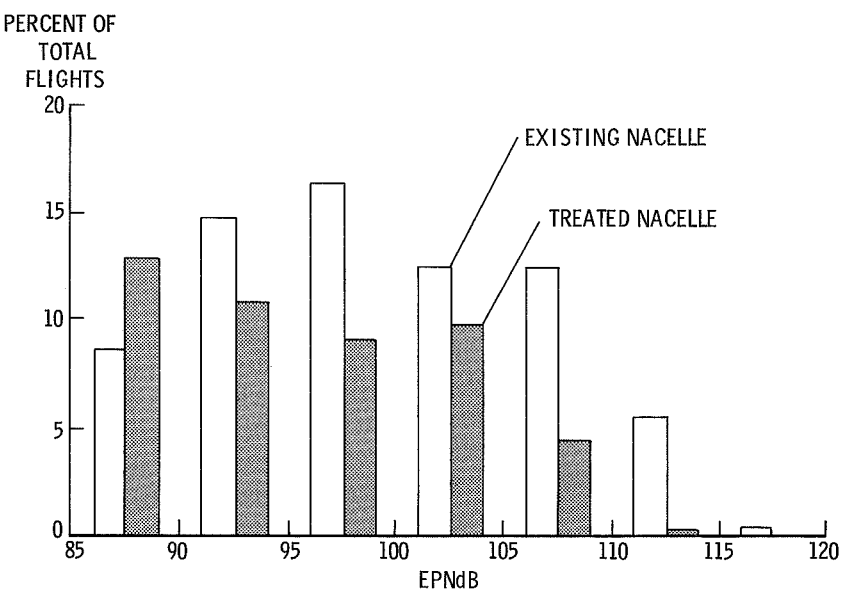

Figure 12.- Take-off noise level distribution at 3.5 nautical miles from start of take-off roll. 707-320B; P&W JT3D-3B engines.